Tests of a new radiation parameterization: "BUGSRAD"

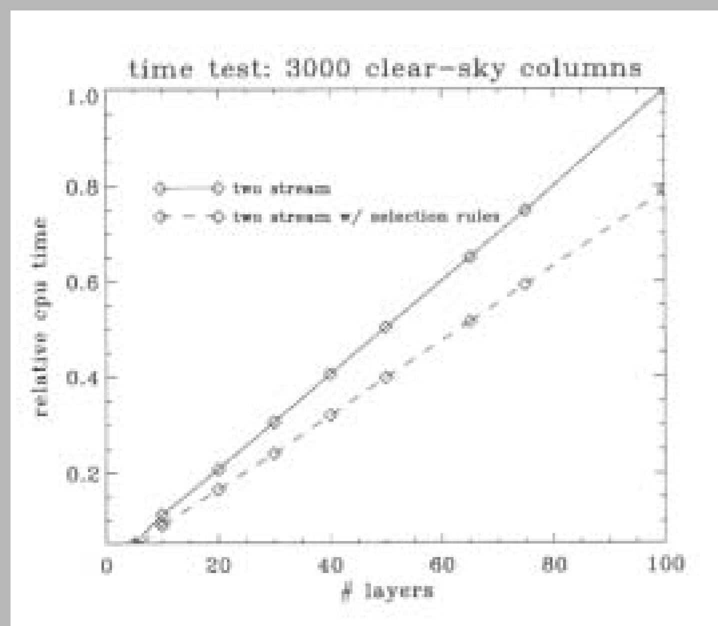
Parameterization developed by Graeme Stephens and colleagues.

Currently being tested in both the CSU GCM and CAM 2. Tests in the CSU GCM are being carried out by Laura Fowler, who identified the issues discussed in this presentation.

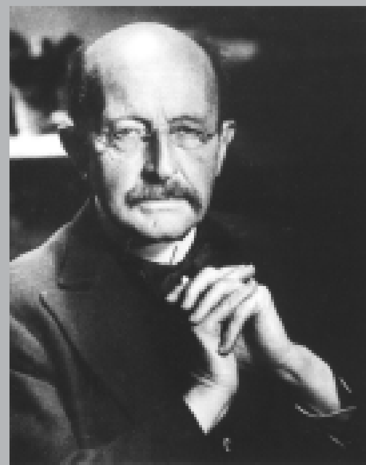
BUGSRAD

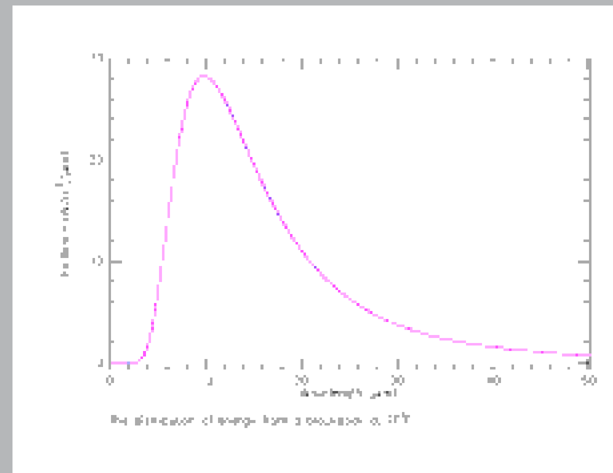
We are very pleased to be testing this new parameterization, which promises many benefits compared to the older parameterization developed by Harshvardhan:

- Better spectral accuracy in both the longwave and shortwave
- The flexibility to accommodate a wide range of trace gases, as well as aerosols
- Linear scaling with the number of layers -- very important for models with high vertical resolution



Surface emission: Planck's Law



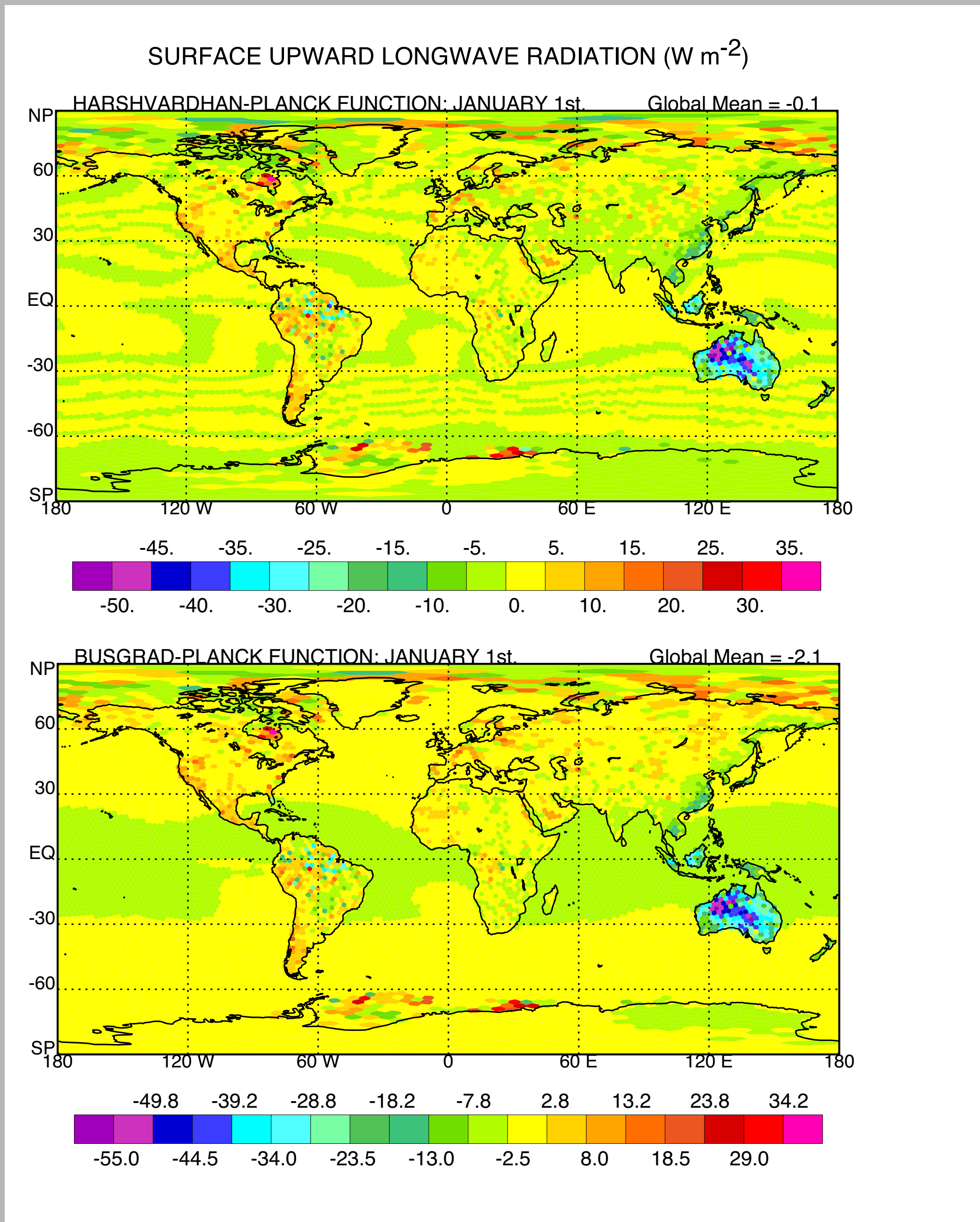


Max Planck derived the wavenumber-dependence of black-body emission:

$$B(T, \upsilon) = \frac{c_1 \upsilon^3}{\left[\exp\left(\frac{c_2 \upsilon}{T}\right) - 1\right]}.$$

This integrates to

$$2\pi \int_0^\infty B(T, \upsilon) d\upsilon = \sigma T^4.$$



These are plots of the instantaneous upwelling longwave radiation as computed in the GCM, minus σT^4. The surface emissivity is assumed to be unity everywhere. In these plots, zero is good.

The top plot is for the older Harshvardhan parameterization, and the bottom plot is for BUGSRAD.

Both parameterizations drastically under-predict the emission over Australia, where the ground is very hot.

There are additional systematic errors, especially in the tropics with BUGSRAD.

The problem

As currently parameterized, the spectral emission becomes inaccurate for temperatures warmer than about 290 K or colder than about 190 K.

- For very warm but physically realizable temperatures, the emission is seriously under-predicted. This will favor further warming -- a positive feedback.
- For very cold but physically realizable temperatures, the emission from individual bands can actually become negative!

These errors stem from the nature of the curve fits to the Planck function, as used in the parameterization of the spectrally varying emission.

Question: How wide-spread is this problem?

How the emission is parameterized

For each of 12 longwave bands, the temperature-dependence of the emission is fit with a polynomial in temperature. For band j, the emission is given by

$$e_j = \sum_{i=0}^{I} c_{i,j} T^i ,$$

where I is the degree of the polynomials.

To specify the emission by each of J bands, we need to assign the values of $(I+1)J$ coefficients.

For example, with fourth-degree polynomials and 12 bands, we have to assign the values of 5x12=60 coefficients.

A simple solution

We can guarantee that

$$\sum_{j=1}^{J} e_j = \sigma T^4$$

simply by requiring that

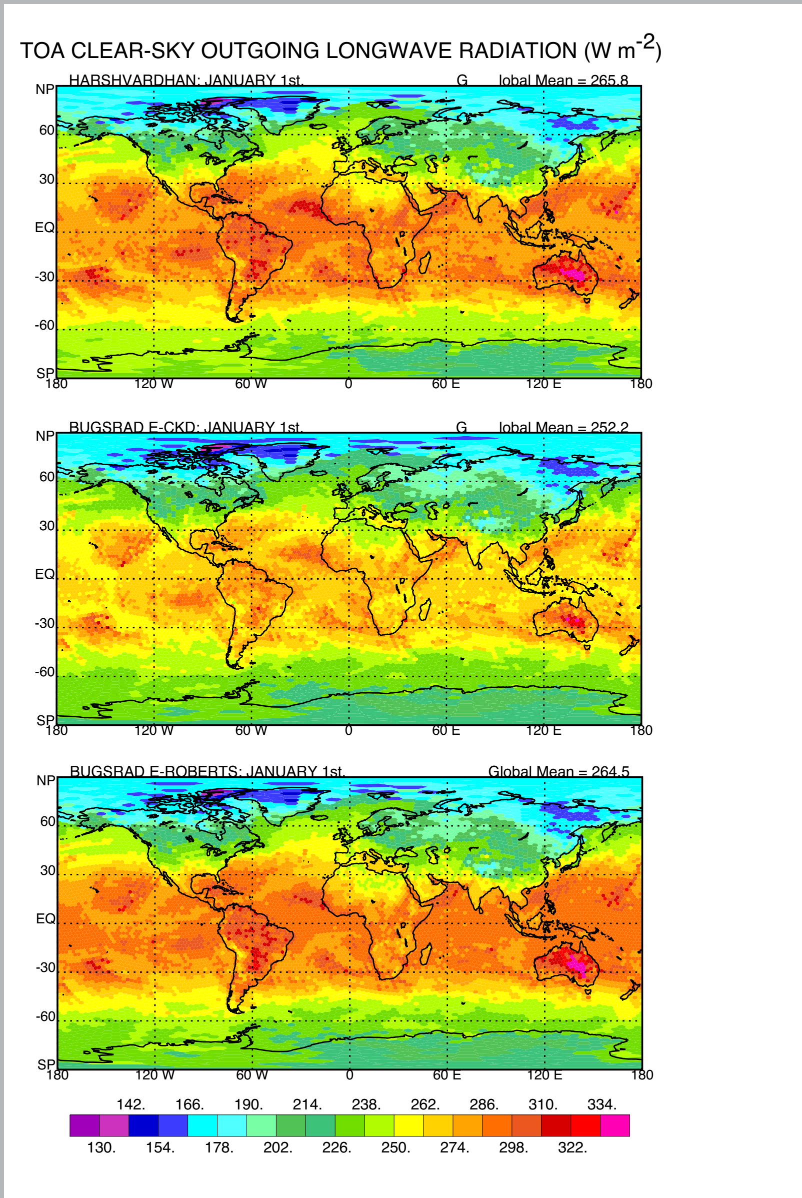
$$\sum_{j=1}^{J} c_{4,j} = \sigma \text{ and } \sum_{j=1}^{J} c_{i,j} = 0 \text{ for } i \neq 4.$$

The number of constraints is $I+1$. This leaves $(I+1)(J-1)$ coefficients still undetermined -- plenty of freedom left with which to optimize spectral accuracy.

The coefficients can be chosen so as to ensure spectral accuracy over a sufficiently wide range of temperatures, e.g., 140 K to 350 K.

Graeme and colleagues are currently reformulating the emission parameterization, following this approach.

What about the top of the atmosphere?



BUGSRAD with the Clough continuum underpredicts the clear-sky OLR compared to CERES/ERBE.

Harshvardhan with the Roberts continuum gave more realistic results.

BUGSRAD modified to use the Roberts continuum gives improved results, similar to those obtained with Harshvardhan.

Question: Suppose that there is a problem with the Clough continuum such that the clear-sky OLR is seriously under-predicted but surface measurements are realistically reproduced. *What kind of problem would that be?*

Here I have to punt.

Conclusions

- The Planck function must be accurately fit over a sufficiently wide range of temperatures.

- This fit can be done in such a way that the total emission is guaranteed to be σT^4, for any temperature whatsoever. We can impose this constraint without sacrificing spectral accuracy.

- Our preliminary results suggest that the Clough continuum leads to a serious under-prediction of the clear-sky OLR. Further investigation is needed.